Structural Analysis of the In-Vessel CEDM Lower Support

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1. Introduction

The In-Vessel Control Element Drive Mechanism (IV-CEDM) was developed for Small Modular Reactors (SMRs) [1]. The IV-CEDM installation structure which supports the IV-CEDMs inside the reactor vessel was also designed [2]. The IV-CEDMs and the IV-CEDM installation structure are connected by the IV-CEDM lower support as shown in Fig. 1.

The stepping load occurs consistently in the magnetic jack type CEDM during operation. So the maximum stress of the lower support shall be less the fatigue endurance limit. Since the maximum stress is likely to occur at the geometrically discontinued point, it is important to minimize stress concentration.

To minimize stress concentration, the IV-CEDM lower support has fillet at the corners of the flow areas. As far as stress concentration is concerned, the fillet radius should be as large as possible. But larger fillet radius reduces the flow area, which requires additional efforts to evaluate its impact on pressure drop of reactor coolant. Therefore, it is desirable to maintain the flow area as possible to minimize the effect of the flow area.

In this paper, optimization of fillet radius to minimize the maximum stress while maintaining the flow area is performed by parametric analyses. The reduced flow area due to the increment of fillet radius is compensated by decreasing the rib width.

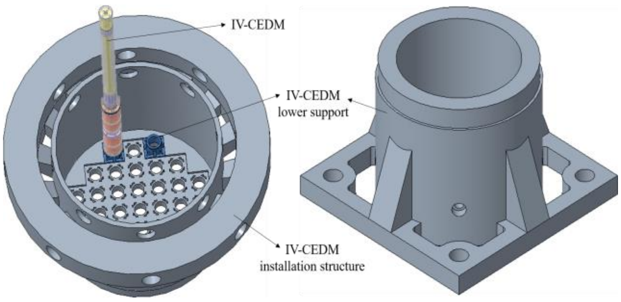

Fig. 1. IV-CEDM installation structure

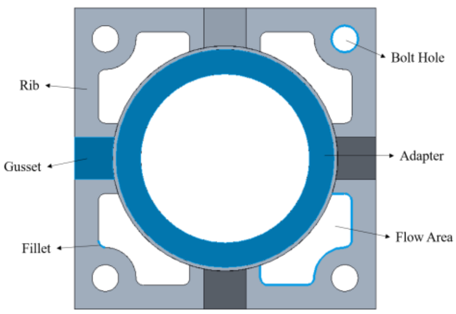

Fig. 2. IV-CEDM lower support

2. Modeling & Analysis

The weakest part of the IV-CEDM lower support is the rib. And the adaptor and gusset are even more stiffer than the rib, which means that the stepping load is transferred to the rib directly. So only the rib is modelled.

As the structure of the IV-CEDM lower support is symmetric, only 1/4 finite element model is generated with SHELL181 element using ANSYS Workbench 19.2 [3].

Material properties of 300 series stainless steel at normal operating temperature are used [4].

Edge of the bolt hole is fixed, and 1/8 of stepping load is applied on the two symmetric lines of 1/4 finite element model, respectively.

Variables of the analysis are the fillet radius and the width of the rib. For larger fillet radius cases, the rib width is adjusted to maintain the flow area same. The analysis cases are shown in Fig. 3.

Mesh optimization is performed using Case A because it is predicted to have the largest stress concentration due to the smallest fillet radius. The mesh size is decided so that the stress changes less than 1% as the number of the element increases.

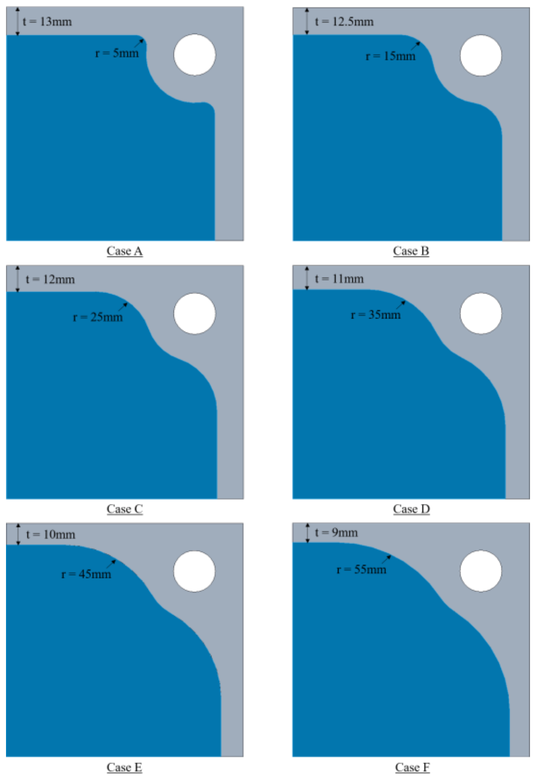

Fig. 3. Analysis cases

3. Results & Review

Fig. 4 shows the stress distribution of each case. The weakest points where the maximum stress occurs are different depending on the analysis cases. In Case A, stress concentration occurs at the corner of the flow area as predicted. The maximum stress is 1.66 times the average stress produced at the minimum cross section of rib.

Fig. 5 shows the fatigue margin of the three weakest points; fillet, bolt hole, and rib center. The fatigue margin is defined as the ratio of the maximum stress to fatigue endurance limit given in ASME Boiler and Pressure Vessel Code Section III [5]. As the fillet radius increases, stress concentration is relieved. Meanwhile, stress at the rib increases as the rib width becomes thinner to maintain the flow area. As a result, the optimum case to minimize the maximum stress is Case C (fillet radius of 25mm) which has significantly improved margin comparing to the initial case, Case A.

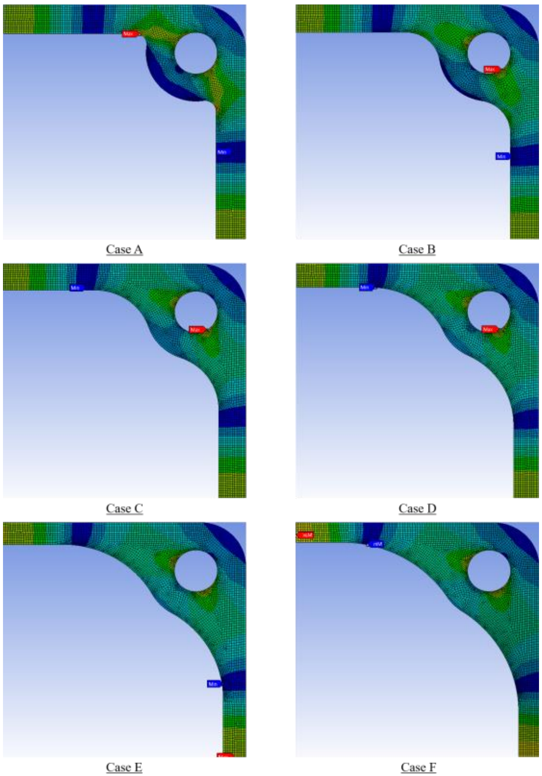

Fig. 4. Stress distribution

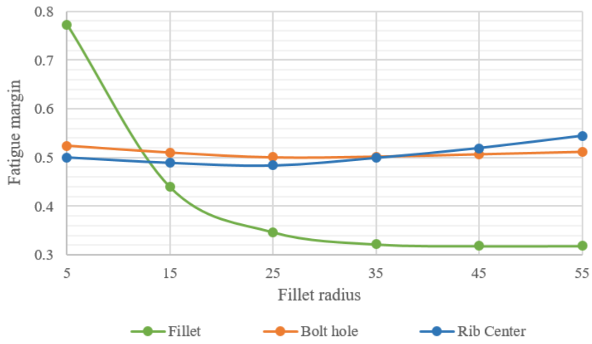

Fig. 5. Fatigue margin

4. Conclusion

In this paper, analyses were carried out to minimize the maximum stress of the IV-CEDM lower support. Cases with various fillet radius of the flow area were modeled to have the same flow area by reducing the rib width. The best case was found to secure about 30% more margin than the initial case.

Although the bolt hole edges are fixed in this paper for simple preliminary study, more realistic boundary condition will be needed for more accurate quantitative result.

Also loadings other than the stepping load such as the flow induced vibration and seismic load are to be considered in future work as their directional loading characteristics can change the optimization result.

REFERENCES

[1] J. S. Park, M. G. Lee, S. G. Chang, D. H, Lee, Conceptual Design of a Magnetic Jack Type In-Vessel Control Element Drive Mechanism, Trans. Korean Soc. Mech. Eng. C, Vol. 3, No. 3, pp. 225~232, 2015.

[2] W. H. Lee, J. S. Park, M. G. Lee, H. M. Kim, Conceptual Design of the In-Vessel CEDM Installation Structure, Transactions of the Korean Nuclear Society Spring Meeting Jeju, Korea, May 17-19, 2017.

[3] ANSYS Manual 19.2.

[4] ASME Boiler and Pressure Vessel Code Section Ⅱ, Part D, 2019 Edition.

[5] ASME Boiler and Pressure Vessel Code Section Ⅲ, Division 1-Subsection NB, 2019 Edition.